

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188		
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.						
1. REPORT DATE (DD-MM-YYYY) 12-10-99		2. REPORT TYPE Final		3. DATES COVERED (From - To) 01-10-93 — 31-12-98		
4. TITLE AND SUBTITLE Vibrational Sensing in Benthic Invertebrates Abbreviated Title: Benthic Invertebrates				5a. CONTRACT NUMBER		
				5b. GRANT NUMBER N00014-94-1-0656		
				5c. PROGRAM ELEMENT NUMBER		
				5d. PROJECT NUMBER		
6. AUTHOR(S) Peter A. Jumars				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) School of Oceanography, Campus Box 357940 University of Washington, Seattle, WA 98195-7940				8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Dr. James E. Eckman Biological and Chemical Oceanography, Code 322BC Office of Naval Research, 800 N. Quincy St. Arlington, VA 22217-5660				10. SPONSOR/MONITOR'S ACRONYM(S) ONR		
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER		
12. DISTRIBUTION AVAILABILITY STATEMENT Unlimited						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT This grant funded completion of a number of studies on the effects of fluid motion on small planktonic organisms. It documented the response of some benthic marine invertebrates to prolonged vibrational stimuli at 50-200 Hz, perhaps indicative of energetic, bottom boundary-layer turbulence. It showed that vibrational artifact and flow intensity generally covary in laboratory flumes used for behavioral studies of animals. Most importantly, data analyzed under this grant gave early indication that high-frequency (≥ 40 kHz) low-angle acoustic backscatter could give information on activities of benthic macrofauna at unprecedented spatial and temporal scales.						
15. SUBJECT TERMS High-frequency acoustics, seabed modification, benthic macrofauna, vibrational stimuli						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Peter A. Jumars	
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	UU	2	19b. TELEPHONE NUMBER (Include area code) (207) 563-3146, x.242	

19991220 012

FINAL REPORT

Grant #: N00014-94-1-0656

PRINCIPAL INVESTIGATOR: Dr. Peter A. Jumars

INSTITUTION: University of Washington

PROJECT TITLE: Vibrational Sensing in Benthic Invertebrates

REPORTING PERIOD: 1 October 1993 - 31 December 1998

AWARD PERIOD: 1 October 1993 - 31 December 1998

This long-lived grant supported publications arising from two earlier lines of work funded by ONR. One paper that had awaited our finding adequate chemical analytic expertise concerned our long-past focus on organism effects on sediment transport:

Dade, W.B., R.L. Self, N.B. Pellerin, A. Moffet, P.A. Jumars and A.R.M. Nowell. 1996. The effects of bacteria on the flow behavior of clay-seawater suspensions. *J. Sed. Res.* **66**: 39-42.

It also funded an invited review on this earlier line of inquiry:

Jumars, P.A., J.E. Eckman and E. Koch. 1999. Animals and plants in benthic flows. In B. Boudreau and B.B. Jørgensen, Eds. *The Benthic Boundary Layer: Transport Processes and Biogeochemistry*. Oxford Univ. Press, NY, in press.

It also funded the analysis and writing of several studies on fluid dynamic effects on small, planktonic organisms — that was our focus when the grant began and helped to stimulate our interest in vibrational sensing by larger, benthic animals. The last paper in this lineage is now in review.

Jumars, P.A., J.W. Deming, P.S. Hill, L. Karp-Boss, P.L. Yager and W.B. Dade. 1993. Physical constraints on marine osmotrophy in an optimal foraging context. *Mar. Microbial Food Webs* **7**: 121-159.

Shimeta, J., P.A. Jumars and E.J. Lessard. 1995. Influences of turbulence on suspension feeding by planktonic protozoa; experiments in laminar shear fields. *Limnol. Oceanogr.* **40**: 845-859.

Karp-Boss, L., E. Boss and P.A. Jumars. 1996. Nutrient fluxes to planktonic osmotrophs in the presence of fluid motion. *Oceanogr. Mar. Biol., Ann. Rev.* **34**: 71-107.

Karp-Boss, L., and P.A. Jumars. 1998. Motion of diatom chains in steady shear. *Limnol. Oceanogr.* **43**: 1767-1773.

Karp-Boss, L., E. Boss and P.A. Jumars. Motion of dinoflagellates in a simple shear flow. *Limnol. Oceanogr.*, in review.

This now-completed line of work continues to have high impact and visibility internationally. On its basis Lee Karp-Boss has been invited to give an oral paper on this line of work and Pete Jumars has been asked to give a tutorial on organism-flow interactions at low Reynolds numbers both at the meeting of the American Society of Limnology and Oceanography in Copenhagen in June 2000.

Our primary objective under this grant was to identify important interactions between organisms and acoustics or(and) acoustic-like motions near the sediment-water interface. The reason for this wording is the semantic difficulty in distinguishing other fluid motion from acoustic propagation, especially in the near field of a sound source. Our early work, reflected in the grant title, was on quantifying the responses of macrobenthic organisms to vibrations of known frequency and intensity. We found that prolonged vibrations in the 50-200 Hz range caused digging in the bivalve *Macoma balthica* and we suggested that these frequencies might be indicative of intense near-bed turbulence and impending sediment transport. We also found that flumes used to detect flow effects vibrate, potentially confounding flow intensity and mechanical vibration from the pumps or paddles as potential behavioral cues. These effects were statistically significant, but we explored many other target species with little success in observing consistent effects of vibrations. Response to vibrations varied enormously among and within individuals. As a consequence, the student involved in this work, Nathan Franzen, left graduate school temporarily and then re-entered graduate school in electrical engineering. He was genuinely interested in the more technical aspects of signal processing after working under this grant. The two manuscripts on *Macoma* and flume vibrations, respectively, await further revision by the principal investigator before resubmission:

Franzen, N.C.M., and P.A. Jumars. Sensitivity of the bivalve *Macoma balthica* to substrate vibration. in manuscript.

Franzen, N.C.M., and P.A. Jumars. Vibrational noise of flumes. in manuscript.

The second line of inquiry, concerning potential effects of benthic animals on acoustic propagation, has proven more quickly fruitful. It began with a search through accumulated 40-kHz data from the STRESS (Sediment TRansport Events on Slopes and Shelves) program for correlates of rate of change in acoustic backscatter from the seabed. We found the strongest cross-correlation with the daily pattern of irradiance, suggesting a biological cause: Jumars, P.A., D.R. Jackson, T.F. Gross and C. Sherwood. 1996. Acoustic remote sensing of benthic activity: A statistical approach. *Limnol. Oceanogr.* **41**: 1220-1241.

This hypothesis, in turn led to work funded by other ONR grants to test by manipulation the effects of organisms on acoustic backscatter (ORCAS and DRI programs) and to resolve the more rapid changes seen at higher acoustic frequencies (300 kHz, STRATAFORM). It also was the data set that first turned our attention to emergence behavior by benthic or partly benthic organisms. Less directly and in part with insights gained from the work in the paper by Dade et al. cited first in this report, this line of research also led us to pursue the potential effects of bacteria on acoustic propagation through sands (DRI-funded Ph.D. dissertation of Jill Schmidt). All of these various field manipulations in the context of large, multi-PI field programs led us to conclude that a portable field laboratory to test organism effects on sound propagation would be cost effective in focused hypothesis testing about biological causes of acoustic effects. The PI continues to pursue this line of work because of its promise in remote sensing of benthic organism activities and abundances and the potential contribution to mine detection and classification (for which problem the biological effects represent "noise").

Their citations also make it clear that work produced under this grant contributed substantially to two national awards to the PI, the Hutchinson Medal of the American Society of Limnology and Oceanography in 1994 and Fellowship in the American Geophysical Union in 1996.